First Results of GaInP-Based Light Sensors for High Energy Physics

Grace E. Cummings, Bob Hirosky, Thomas Anderson, Nicholas Anderson

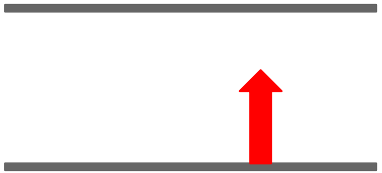
LightSpin Technologies, Inc.

University of Virginia

Why GaInP?

High Energy Physics experiments are high radiation environments. While SiPMs lead in HEP light detection, they are not optimized for radiation hardness. We are looking for Geiger Mode APDs made from materials designed to withstand our harsh radiation conditions.

Large Band Gap
=
Low Thermal Noise



Harder for thermally generated electrons to produce signal

Low Carrier Concentration
=
Less sensitivity to induced defects

Commercially Available Substrate
=
Production ready material

The Devices

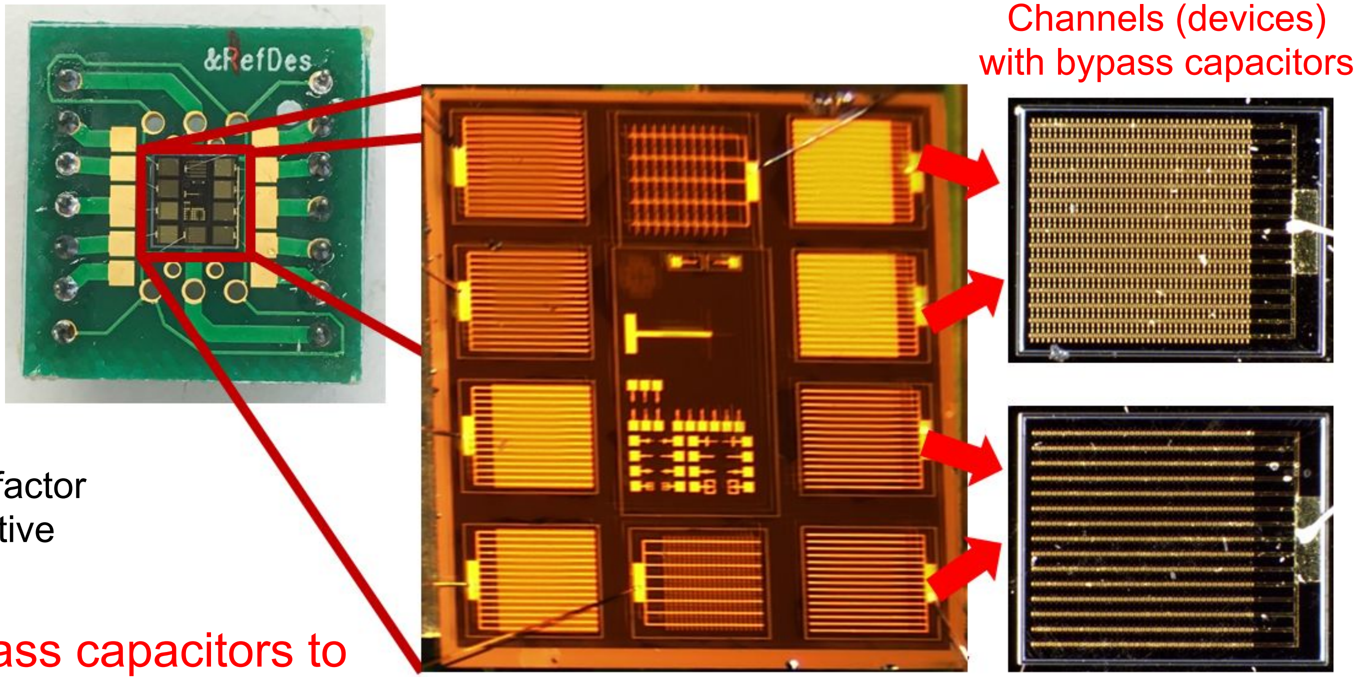
10 devices per chip, two new generations of device

Gen5.1

- AlGaAs window
- Anti-reflective coating

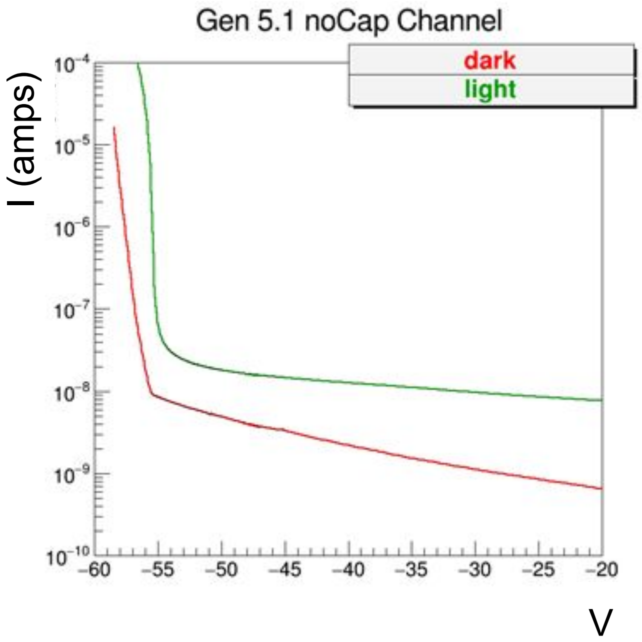
Gen5.2

- Different manufacturer
- AlInP window
- Improvement on fill factor
- Improved anti-reflective coating

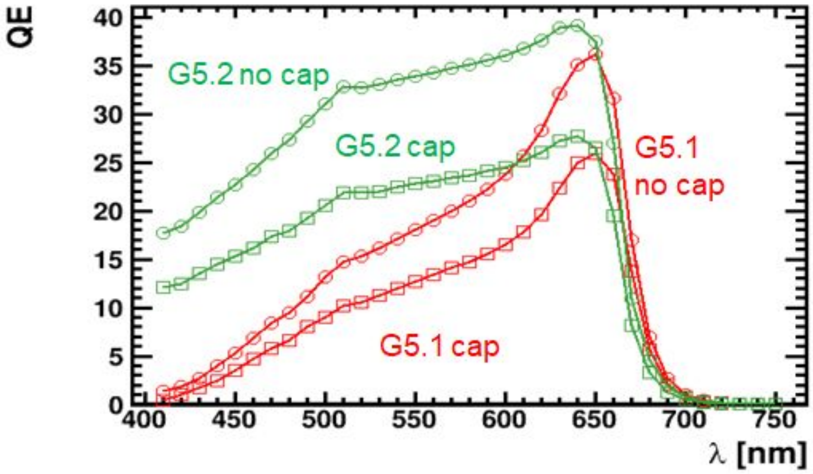


New to this run: bypass capacitors to increase the speed and amplitude of the signal pulse.

Light Sensitivity

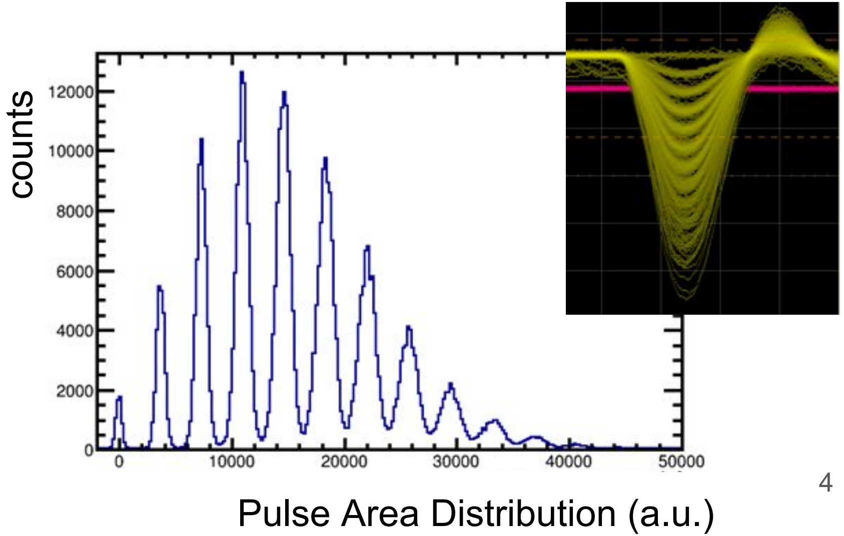


Characteristic “hockey stick” shape of IV curves. Gen5.1 has breakdowns around 55 V, Gen5.2 around 45 V



External quantum efficiency higher for Gen5.2 due to improved anti-reflective coating. Capacitor channels have lower active area.

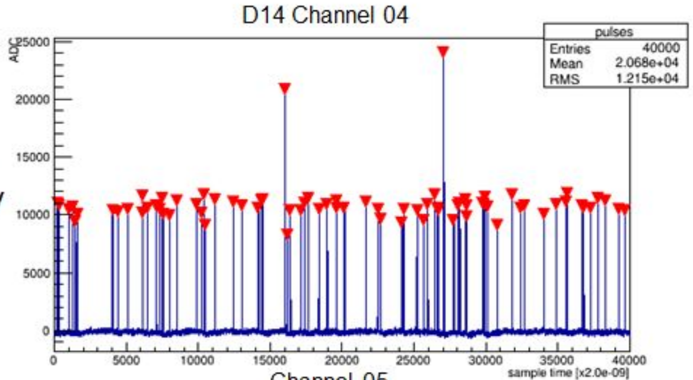
Multiphoton peak resolution, better in Gen5.1



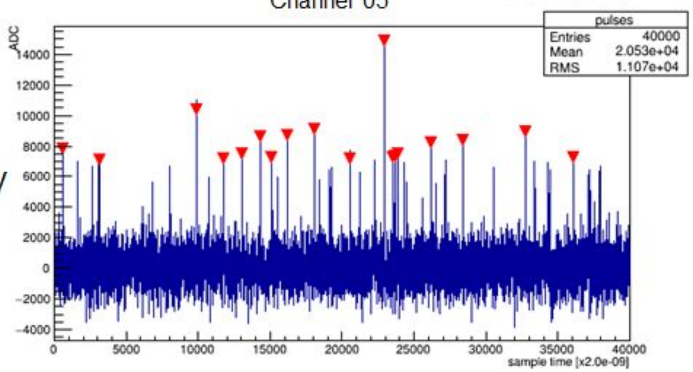
Dark Pulse Comparisons

Gen5.1

V_{ex} = 0.76 V



V_{ex} = 0.85 V



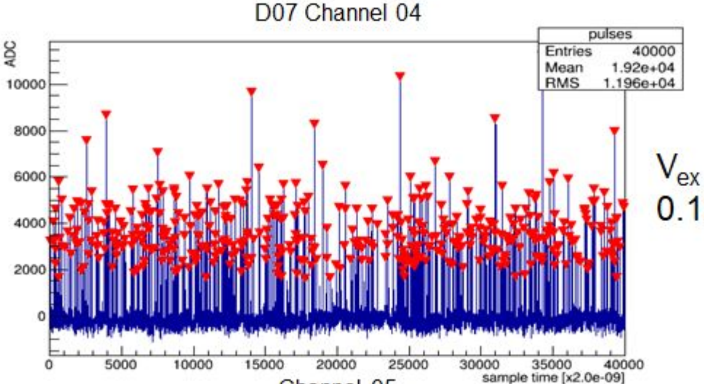
Capacitor Channels

Gen5.1 Quieter

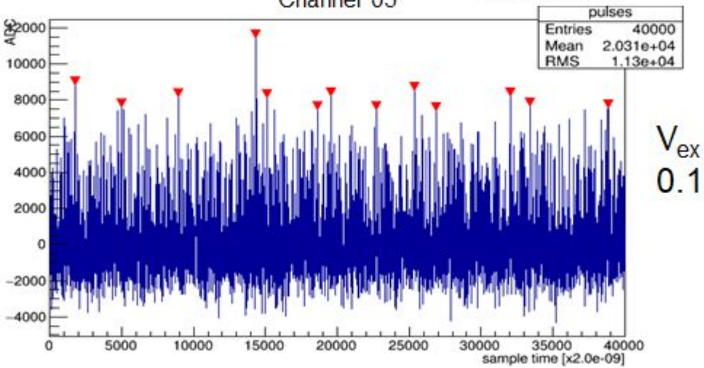
Non-Capacitor Channels

Gen5.2

V_{ex} = 0.12 V

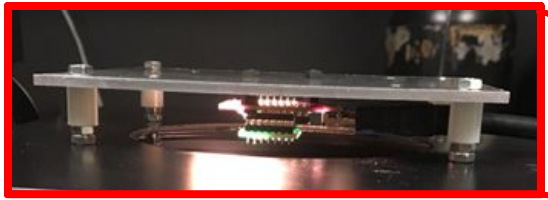


V_{ex} = 0.12 V

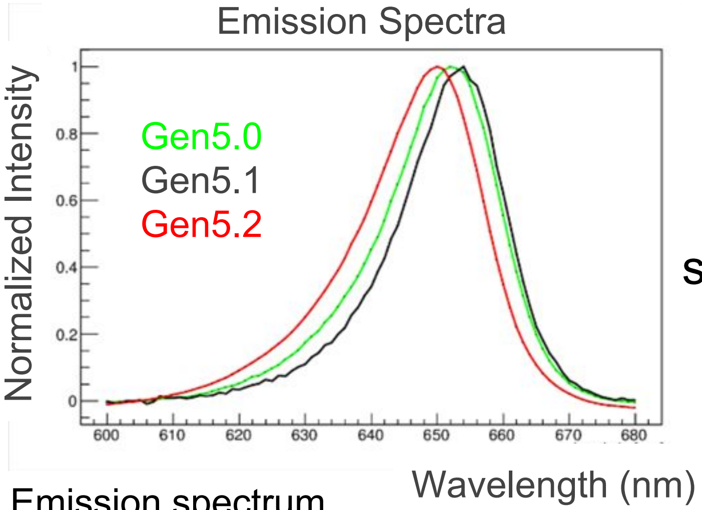


Using light to probe damage

Took 10 second exposures



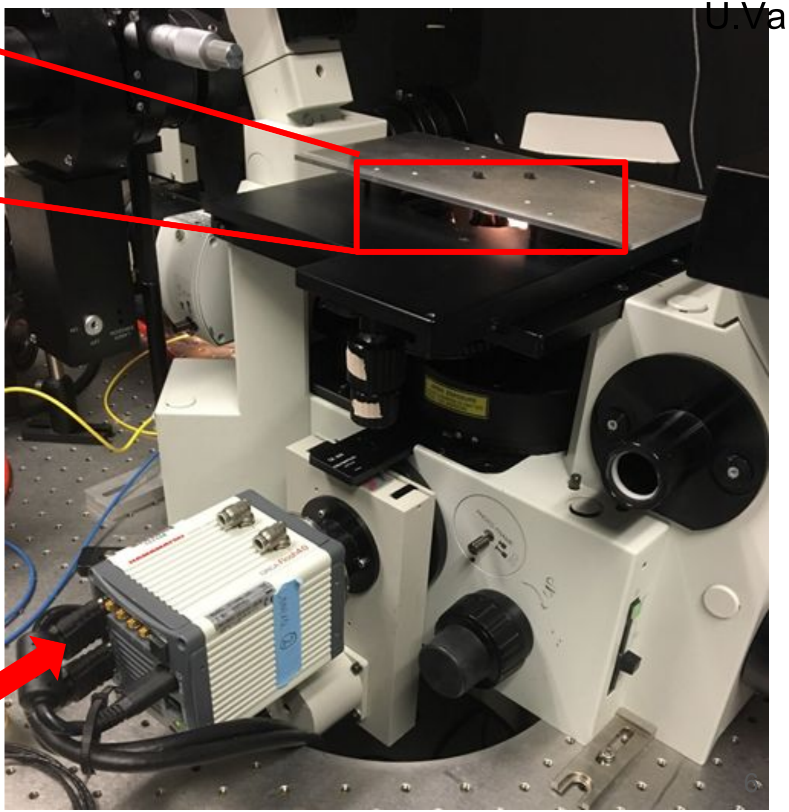
Total Internal Reflectance Fluorescence (TIRF) microscope at the W.M Keck Center for Cellular Imaging at U.Va



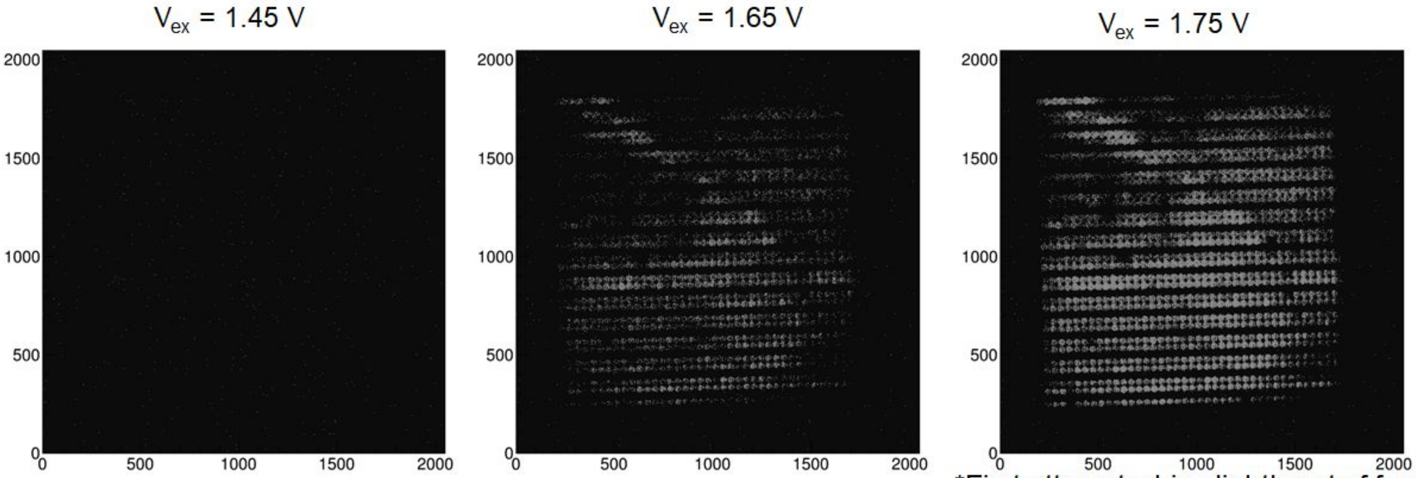
Emission spectrum consistent with 1.9 eV band gap.

Emitted light peaks in the red, so used a red light to focus

Hamamatsu ORCA-Flash4.0 CCD
4 Mpix, QE > 70%



First Illuminations

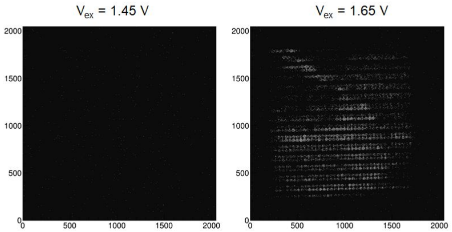


*First attempt, chip slightly out of focus

Gen5.1

On non-irradiated chip, higher overvoltage needed to emit light. Light appears to come uniformly out of entire active area.

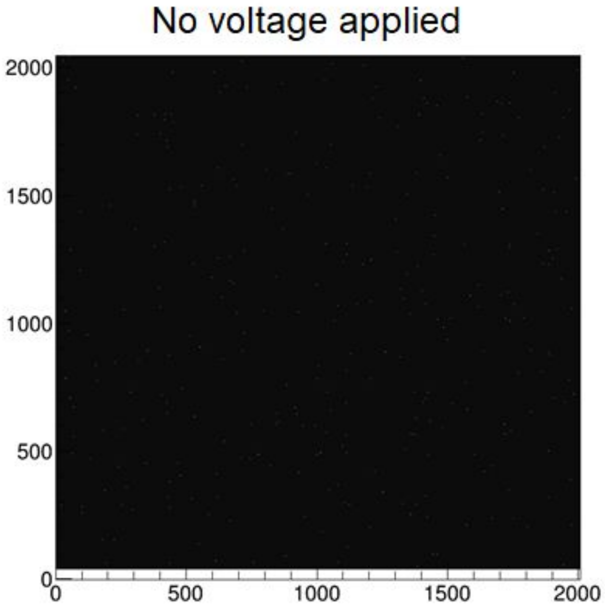
First Illuminations

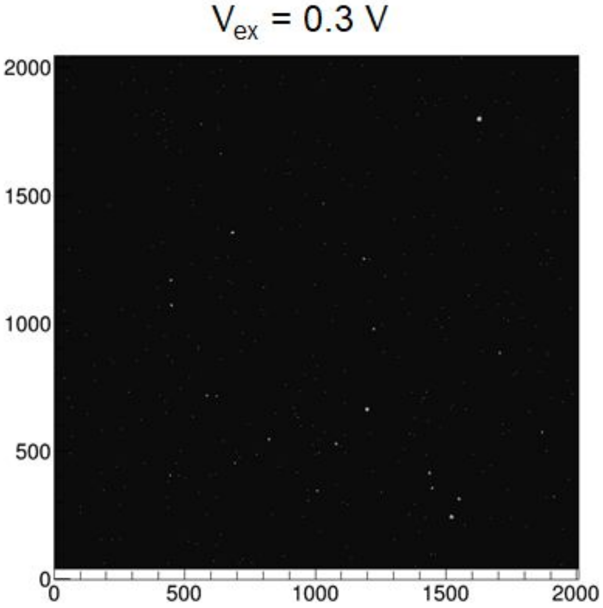


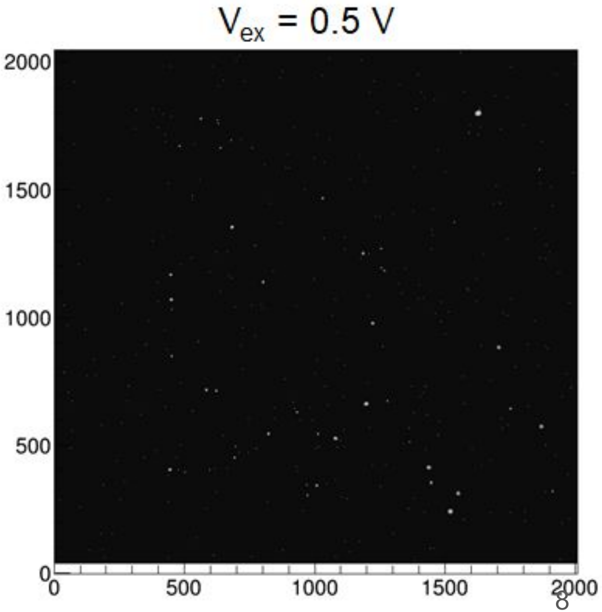
Gen5.1

Gen5.2

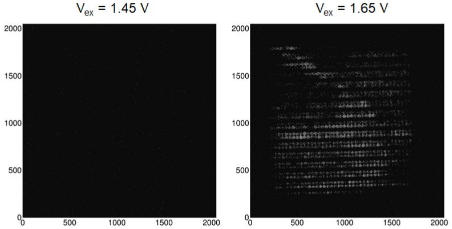
On non-irradiated chip, we saw hotspots at standard overvoltages, indicating crystal defects. **Source of increased dark count rate.**







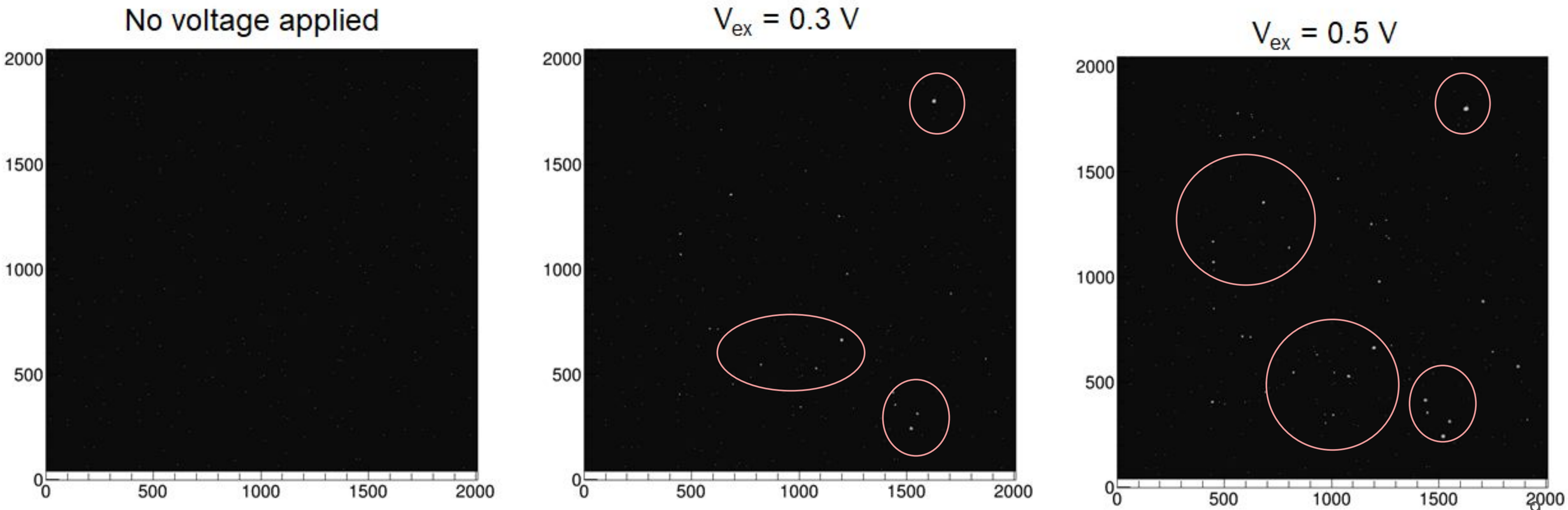
First Illuminations



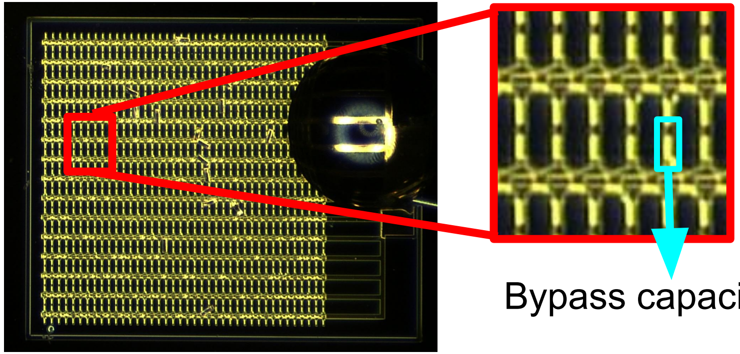
Gen5.1

Gen5.2

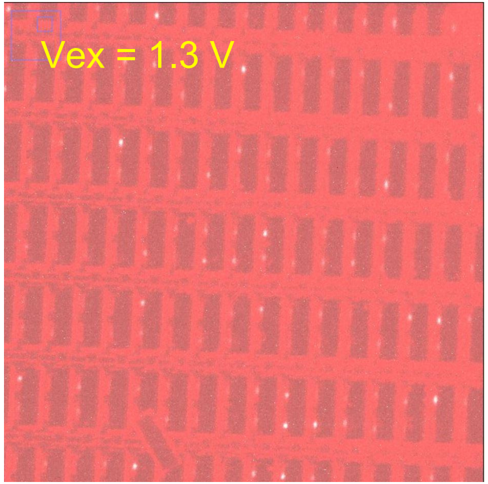
On non-irradiated chip, we saw hotspots at standard overvoltages, indicating crystal defects. **Source of increased dark count rate.**

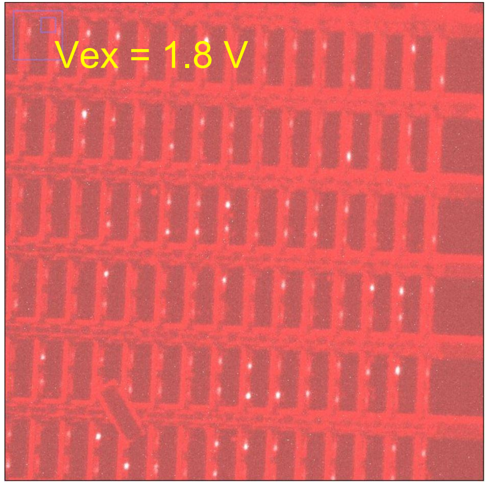


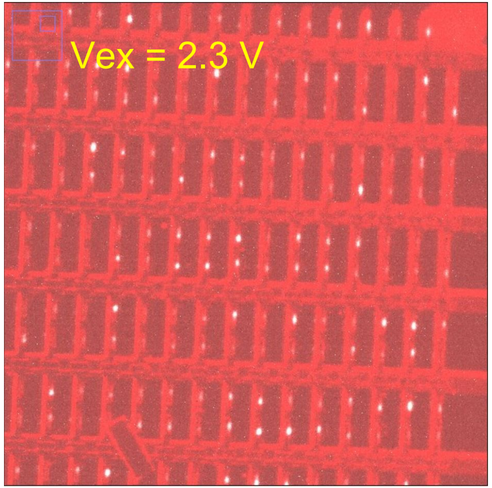
Gen5.1 capacitor channel damage



At first, looks like damage is clustered near the capacitor



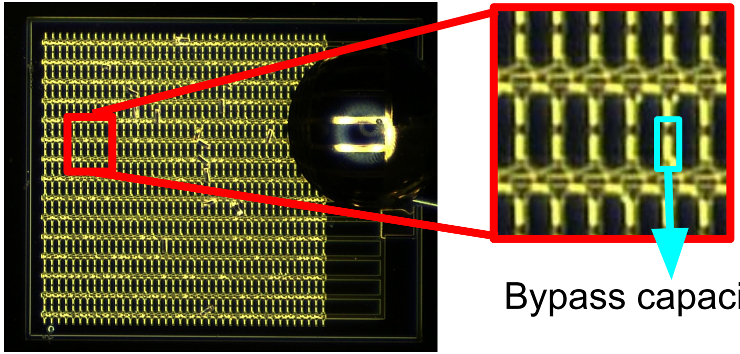


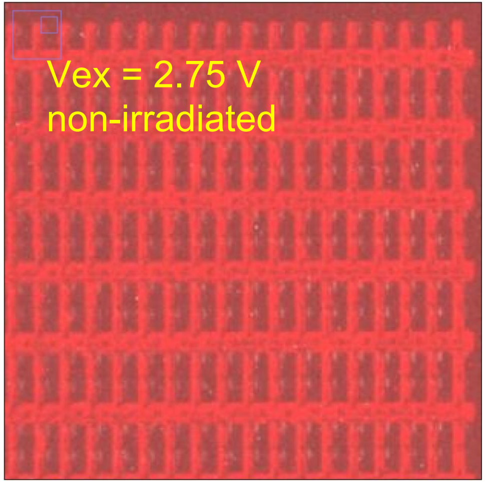


Received 1e12 p/cm^2

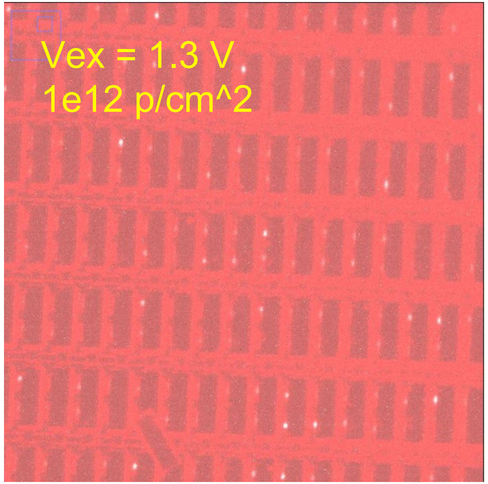
Damage across entire array

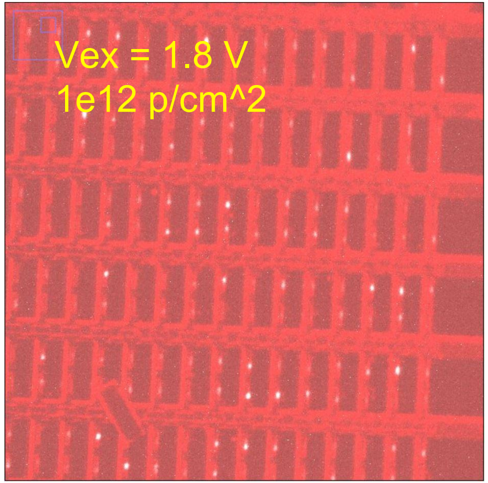
Gen5.1 capacitor channel

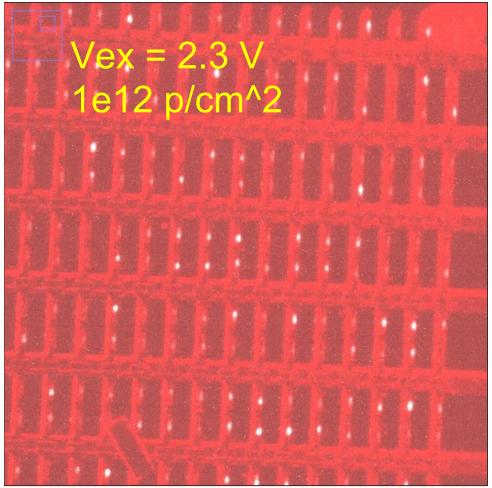




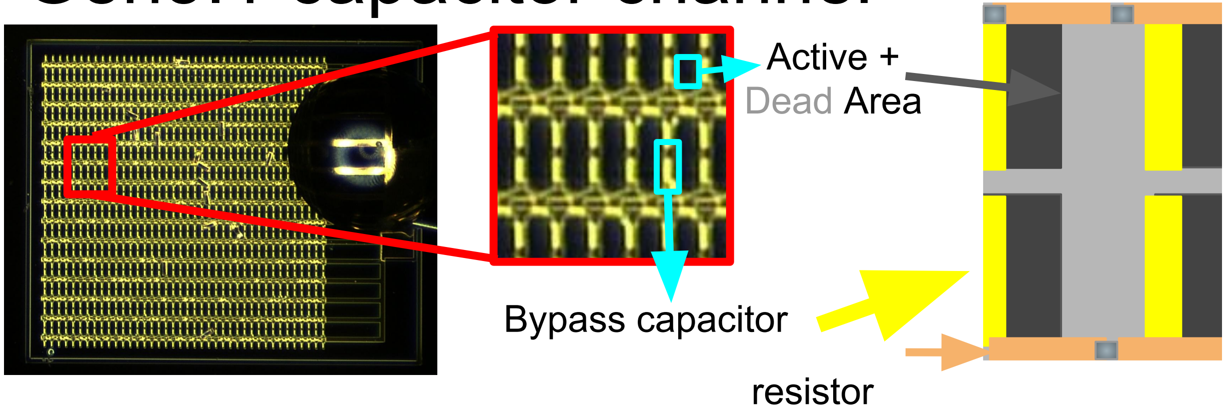
However, radiation damage seems to be in same place as emitted light of unirradiated chips

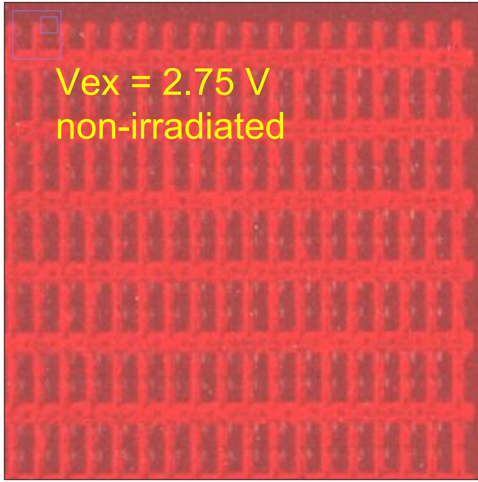


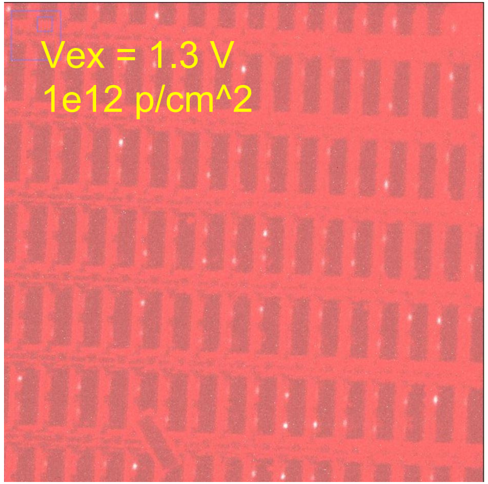


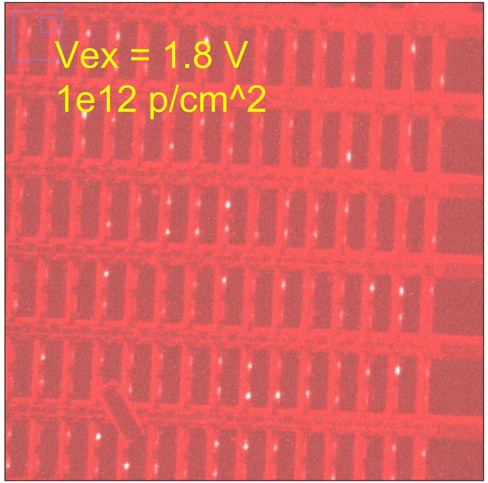


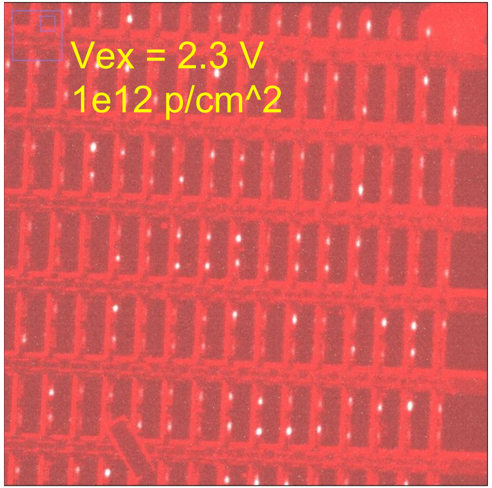
Gen5.1 capacitor channel







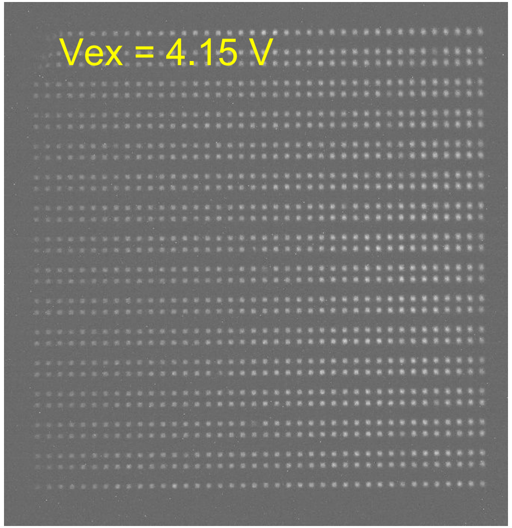


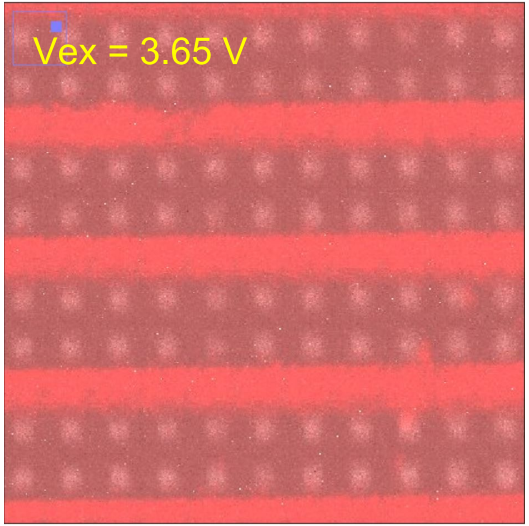


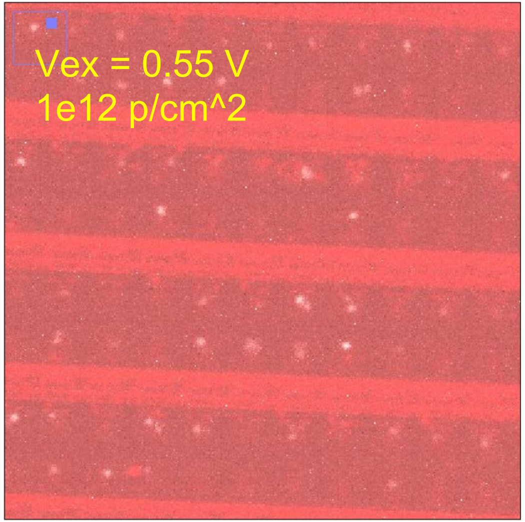
Damage produces hotspots across entire active area, similar to non-irradiated light emission.

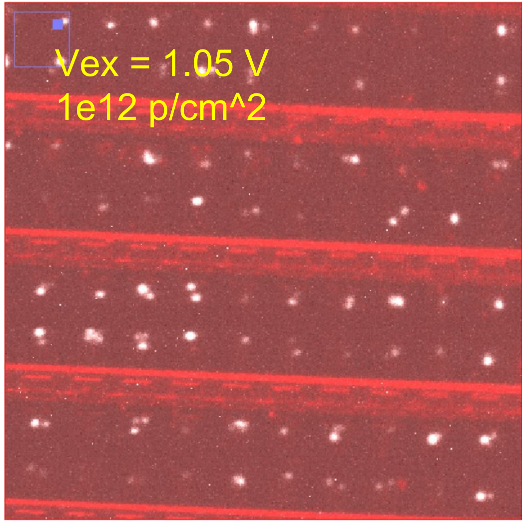
Gen5.1 non cap

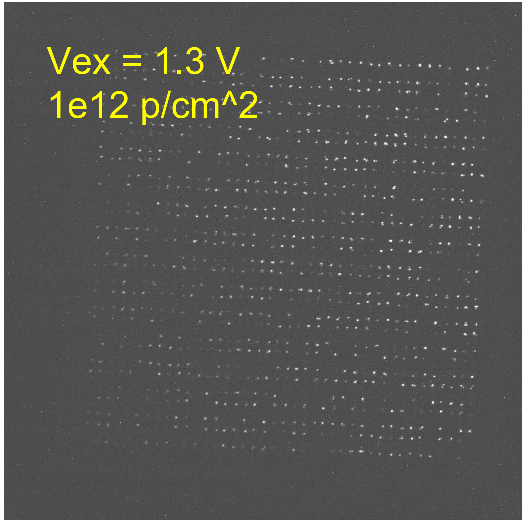
Non-capacitor channels make it clear that the entire active area emits, and reveals that all exposed GaInP takes damage, alluding to lattice damage.











Do not know depth of damage.

Conclusions

Functional Geiger-mode APDs can be made of GaInP

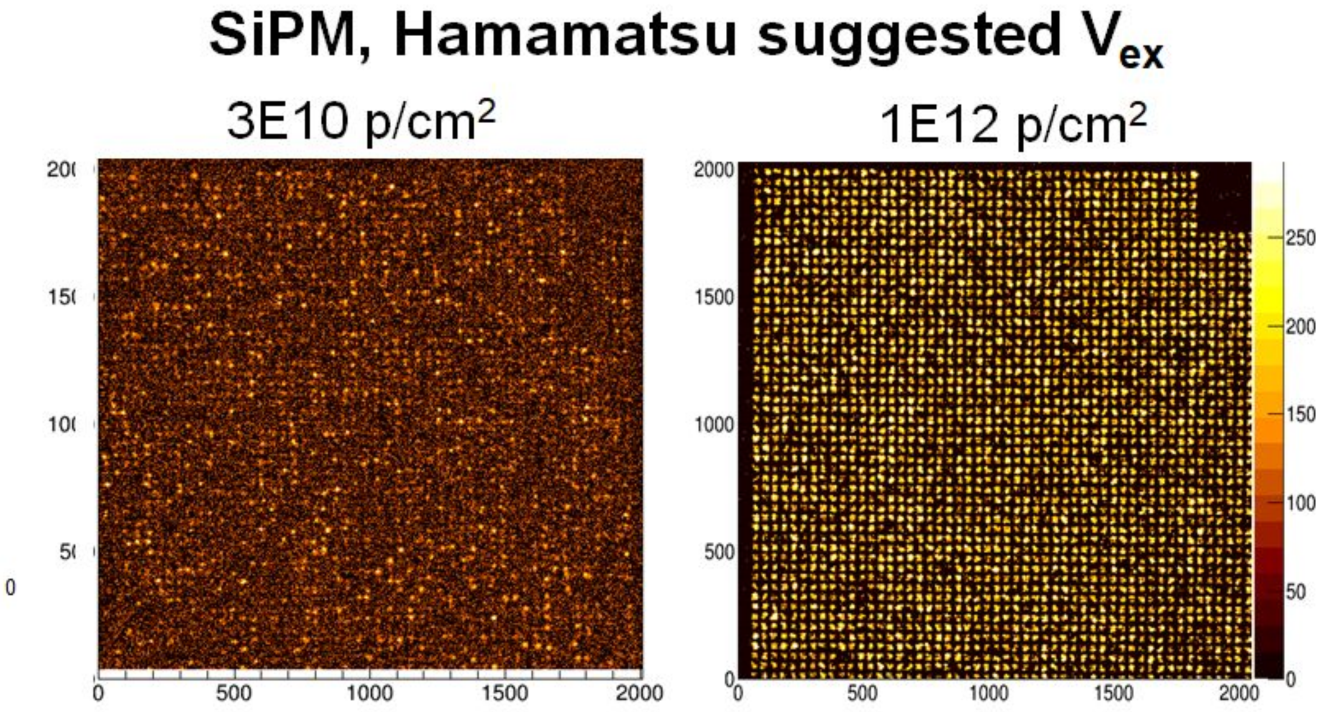
Images of light emission from the devices can be used to understand radiation damage and device active structure

GaInP APDs seem to show similar bulk damage effects to SiPMs, but are far less optimized devices / quality of materials

Gen 6 should arrive this summer, and we will continue radiation damage and light emission studies

More Information and Backup slides

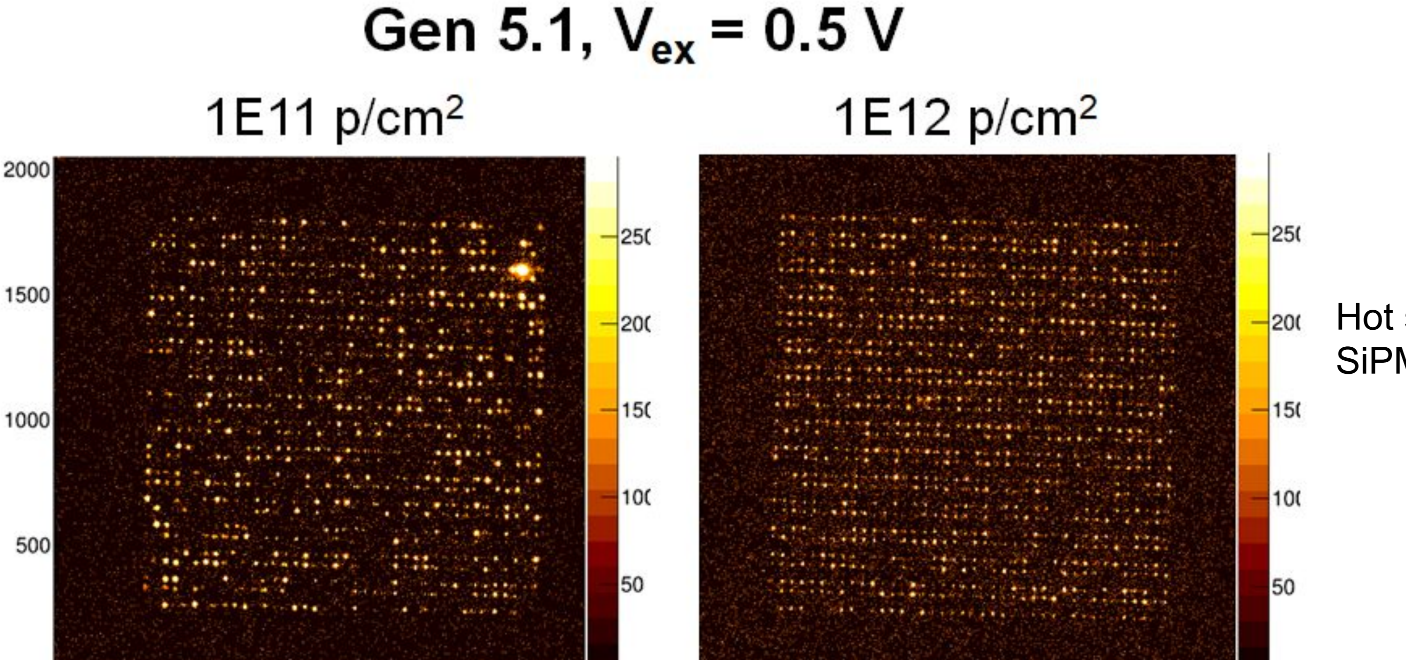
SiPM Damage



SiPMs also have hotspots uniformly distributed across the array.

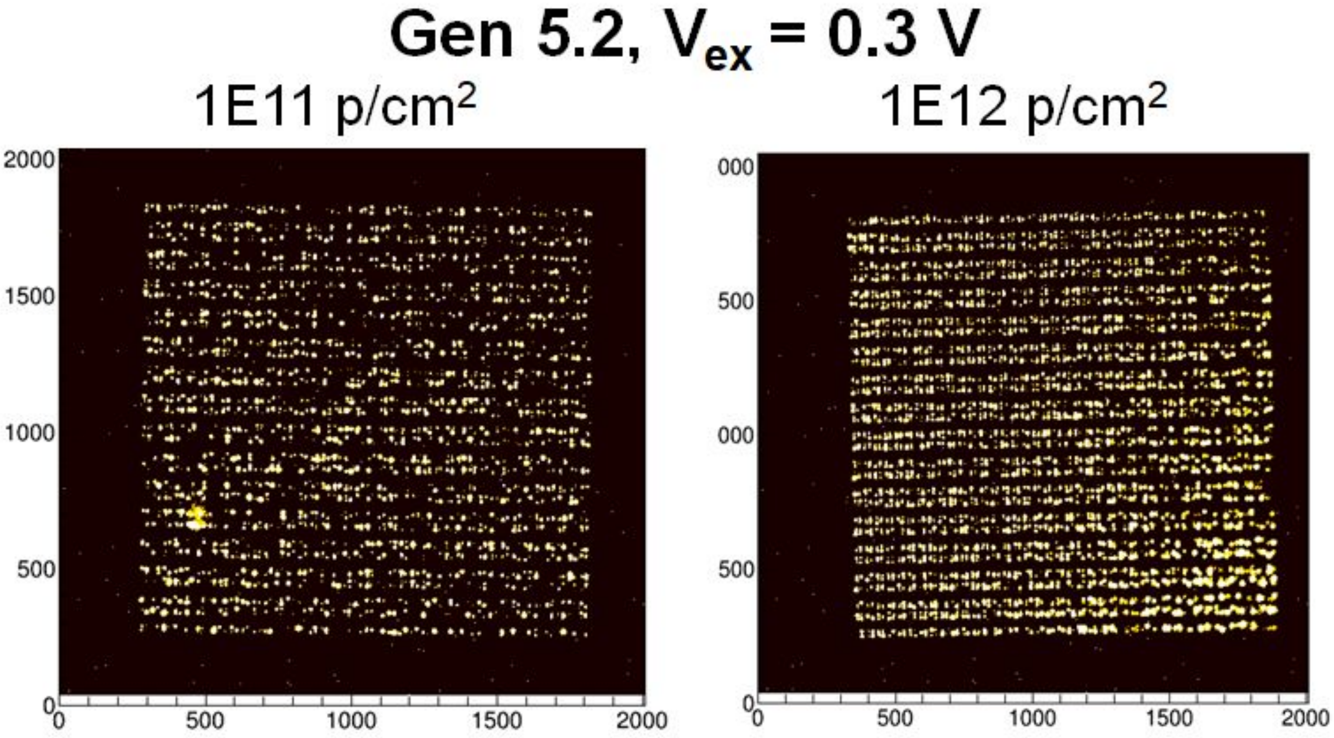
While the SiPM images have less light captured, SiPMs should emit farther into the infrared, which cannot captured by our camera.

Amount of light , Gen5.1



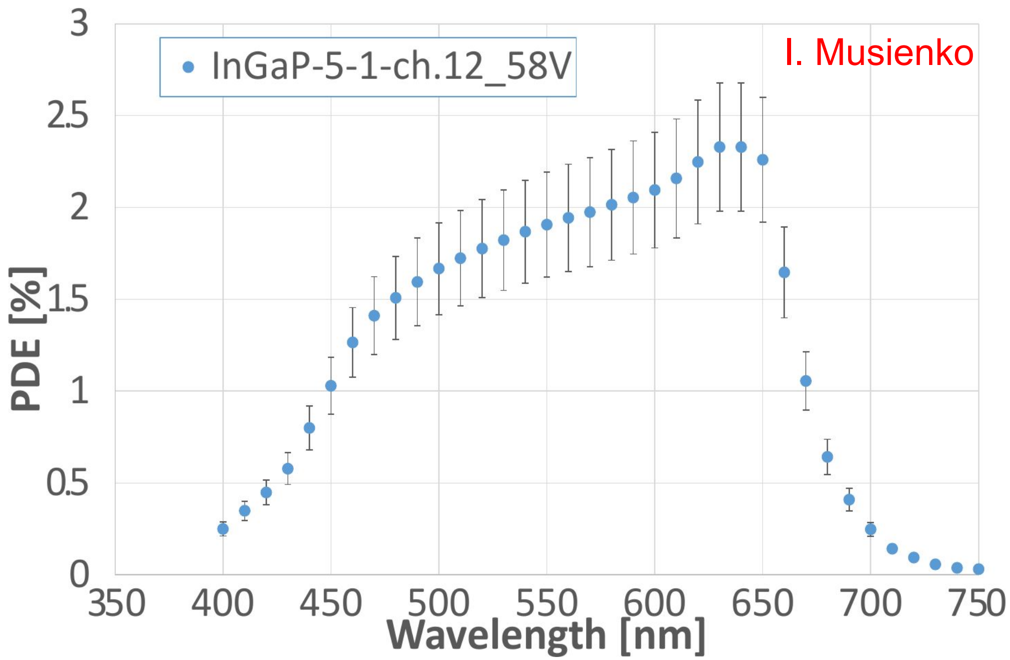
Hot spots burn brighter than SiPMs, but still comparable.

Amount of Light, Gen5.2



Much more light emission due to damage than Gen5.1 or SiPMs

Photon Detection Efficiency



Gen5.1 non-capacitor channel

Device Structure